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Original Article

Quantitative Analysis of the Effects of a Bangerter Filter on Gross Stereopsis in Experimental Models of Reduced Visual Acuity

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Although a 0.3 Bangerter filter, which reduces visual acuity, is frequently used for treating moderate amblyopia, the effects on gross stereopsis are not well known. This study quantitatively evaluated whether gross stereopsis is degraded by a Bangerter filter. Seven healthy subjects (median age: 29 years) participated in this psychophysical study. Targets with crossed disparities of 1°, 2°, 3°, 4°, and 5° were randomly presented on a three-dimensional television display. The subjects indicated the point at which the targets popped out from the television screen (matching method). The distance from the screen to the point was defined as the degree of stereopsis. This experiment was performed with and without a 0.3 Bangerter filter. The corrected monocular visual acuities were decreased to about 20/63 by the filter in all subjects. No significant difference was observed for any of the disparities (1°-5°), between the degree of stereopsis visualized with and without filters for either the dominant or the non-dominant eye. The degree of stereopsis was not degraded by the reduced visual acuity induced by the use of 0.3 Bangerter filters. In this regard, the use of 0.3 Bangerter filters may be considered safer than occlusion eye patches for the patients with normal binocular vision.

Key words: amblyopia, Bangerter filter, binocular vision, stereopsis

Bangerter filters, available since the 1960s, are transparent filters that were designed to be used to modulate the degree of deprivation caused by the use of occlusion eye patches and to produce a diffuse, defocused image that degrades visual acuity in the covered eye to predicted levels [1,2]. It has been reported that the optical characteristics of Bangerter filters did not correspond well with their labeled density designation [3].

Bangerter filters are also considered a reasonable option for the initial treatment of moderate amblyopia [4,5]. Treatment with a Bangerter filter can be beneficial because they are less disruptive to binocular function than occlusion eye patches. The filters are available in a range of strengths (0-1.0); the numerical designation represents the level to which visual acuity is reduced by the filter as designated by the manufacturer. The Pediatric Eye Disease Investigator Group used a 0.3 Bangerter filter for moderate ambly-

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opia patients with visual acuity ranging from 20/40 to 20/63 in the amblyopic eye [5].

Reduced stereoacuity thresholds are commonly associated with reduced visual acuity or with strabismus. Several studies that examined the effects of induced visual acuity deficits on stereoacuity thresholds used either optical blur [6-10] or diffusing filters [11,12]. In addition, some studies have shown an age-related decrease in stereoacuity thresholds [13-15]. The stereoacuity threshold is known to be degraded by reduced monocular visual acuity using Bangerter filters when assessed by random dot tests [16]. However, no reports have quantified the amount of stereopsis perception itself induced by disparities in the presence of Bangerter filters.

Chen *et al.* [17] recently reported on the benefits, in terms of binocularity, of using Bangerter filters for patients with amblyopia. They also noted that if 'gross stereopsis' (*i.e.*, not fine stereoacuity thresholds induced by small disparities, but stereopsis induced by relative large disparities) is not degraded by Bangerter filter use, then children undegoing treatment for amblyopia with these filters can perform outdoor activities of daily living more safely than when they undergo treatment using occlusion eye patches.

In the present study, we evaluated whether gross stereopsis itself is degraded because of reduced visual acuity, by quantifying gross stereopsis using a three-dimensional (3D) television display with and without a Bangerter filter, in a psychophysical procedure.

Materials and Methods

Subjects. Eleven healthy subjects (median age: 29 years; range: 21-35 years; four females, seven males; Experiment 1) with no eye diseases participated in the psychophysical measurements without a Bangerter filter (Ryser Optik, St. Gallen, Switzerland). Seven of the subjects (median age: 29 years; range: 21-35 years, three females; Experiment 2) agreed to participate in the measurements using Bangerter filters. The exclusion criteria were the absence of stereopsis under the conditions used in this study. The subjects wore their usual glasses or contact lenses during the experiment. The corrected unilateral visual acuities were 20/16 or better in all subjects.

Experiment 1. Targets with crossed disparities made by computer graphics were randomly presented on a frame sequential 3D television display (50-inch, TH-P50VT3, Panasonic, Osaka, Japan). We adapted the targets to consist of only combinations of fine lines, to avoid monocular cues as much as possible. The disparities were 0, 1.05, 2.10, 3.20, 4.20, and 5.20 cm on the monitor, which were approx. 0°, 1°, 2°, 3°, 4°, and 5° (0, 3,600, 7,200, 10,800, 14,400, and 18,000 sec of arc, respectively, Fig. 1). The disparities θ (°) were calculated using the following Equation (1):

$$\theta = 2\left[atan\left\{\frac{(P+T)}{2D}\right\} - atan\left(\frac{P}{2D}\right)\right] \quad (1)$$

where P (cm) is the interpupillary distance (PD) of the subject, T (cm) is the disparity on the screen, and D (cm) is the distance between the subject and the TV screen. PD changes the θ, but only slightly. For example, a 1.05-cm disparity in a subject with a 7.2-cm PD is 0.9998°, and that in a subject with a 5.6-cm PD is 1. 0006° in the same setting with a 60-cm distance between the subject and the TV screen. Actually, commercial stereoacuity charts are designed as the disparities on the chart are constant.

The subject was in a fixed position achieved using a front headrest placed 60 cm away from the display. The subject wore 3D glasses with an active shutter system (TY-EW3D2MW, Panasonic) during the experiments. If the subject had normal stereo vision, he or she could see the summit point of pyramid images pop out from the television screen when s/he viewed the targets. The subject indicated the point at which the targets appeared to pop out from the television screen by placing the tip of a pen on the apex of the pyramid

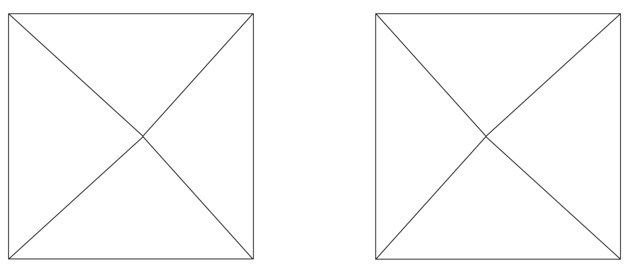

Fig. 1 Targets with crossed disparities. If the subjects have normal stereo vision, they can see the summit of the pyramid rise out of the screen when they look at the targets. We adapted the targets to consist of only combinations of fine lines in order to avoid monocular cues as much as possible. The outer frame is a square 30° on a side when converted to the visual angle.

(the "matching method" in psychophysical terms). An examiner measured the distance from the screen to the tip of the pen; this was defined as the degree of stereopsis (cm).

To evaluate the validity of the test, the same series of tests was conducted for a second time after the subject rested for a few minutes. Because the degree of stereopsis of a subject with a longer PD is smaller than that of a subject with a shorter PD, the degree of stereopsis cannot simply be compared. To eliminate the influence of PD, the ratio of the degree of stereopsis (%, RDS) to a geometric theoretical value in each subject was used for the statistical analysis. The geometric theoretical value S (cm) was calculated using the following Eq. (2):

$$S = D \times \frac{T}{(T+P)} \tag{2}$$

where D (cm) is the distance between the subject and the TV screen, T (cm) is the disparity on the screen, and P (cm) is the PD of the subject.

The correlation between RDS and stereoacuity was confirmed. We used the TNO test (Lamèris Ootech BV Nieuwegein, the Netherlands) to measure the stereoacuity thresholds (retinal disparities ranging from 15 to 480 sec of arc) at a distance of 40 cm.

Experiment 2. Acquired monocular reduced visual acuity models were made using a 0.3 Bangerter filter. This particular experiment was performed with 0.3 Bangerter filters for 2 different tests. The filter was placed on the surface of the 3D lens in front of the dominant eye or the non-dominant eye of the subject at different times in random order. We assessed whether the degree of stereopsis was different under normal (without Bangerter filters) and reduced visual acuity conditions using Bangerter filters.

The intensity of illumination was 660 lux for this experiment measured using a Digital Lux Meter LX-1334 (Custom Co., Tokyo, Japan).

Statistical analysis. All statistical analyses were performed using SPSS version 21 (IBM, New York, NY, USA). The Mann-Whitney U-test was performed on unpaired sets of data. The Wilcoxon signed-rank test was performed on paired sets of data. Correlations were analyzed using Spearman's rank correlation coefficient. P-values < 0.05 were considered significant. Since a total of three comparisons were performed for the degree of stereopsis, with and without filters, we applied the Bonferroni correction for multiple comparisons, and we determined that the corrected threshold for significance was 0.017.

Ethics statement. This study was approved by the Ethics Committee at Okayama University, Graduate School of Medicine, Dentistry, and Pharmaceutical Sciences (Okayama, Japan) and adhered to the tenets of the Declaration of Helsinki. The study received a waiver of written informed consent because the research involved no more than minimal risk to subjects. We received verbal consent from all subjects.

Results

All subjects perceived gross stereopsis under the conditions of this study, with and without the Bangerter filter. The stereoacuity was 60 arc seconds or less measured using the TNO test in all subjects.

Experiment 1. Fig. 2 shows the association between the average degree of stereopsis and the theoretical values. The average (±SD) degrees of stereopsis without a 0.3 Bangerter filter in the 1°, 2°, 3°, 4°, and 5° crossed disparities were 7.7 (±1.0) cm, 13.5 (±1.4) cm, 18.6 (±1.6) cm, 22.1 (±2.3) cm, and 25.4 (±2.1) cm, respectively. The average (±SD) RDS values against the geometric theoretical values were 89.6% (±10.4), 89.8% (±8.1), 91.9% (±7.6),

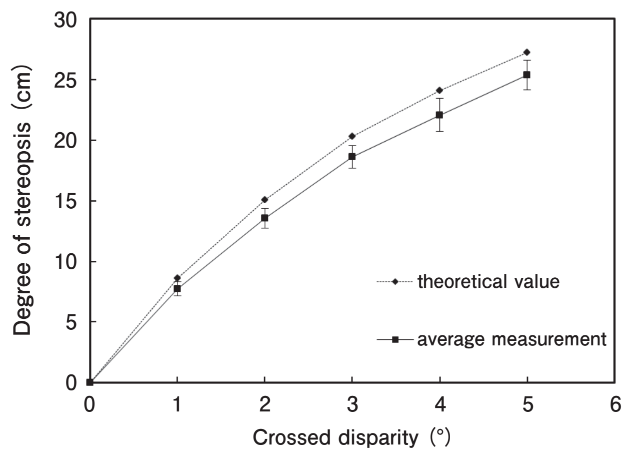

Fig. 2 The relationship between the average degree of stereopsis and theoretical values. Although the average measurements in all crossed disparities (1°, 2°, 3°, 4°, and 5°) are significantly smaller than the theoretical values, the respective rates are similar. The y-axis is the average degree of stereopsis adjusted to an interpupillary distance of 6.5 cm. The bars are 1.96 × the standard errors of the subjects.

91.7% (±9.5), and 93.4% (±8.3), respectively. The median values (used for the statistical analysis) were 95.2%, 92.9%, 92.0%, 90.0%, and 96.2%, respectively. There was a significant difference in the median values and 100 (%) as a theoretical value ($p=0.006$, 0.003, 0.016, 0.021, and 0.021, respectively); the measured value was significantly lower than the theoretical value. However, the respective rates were similar.

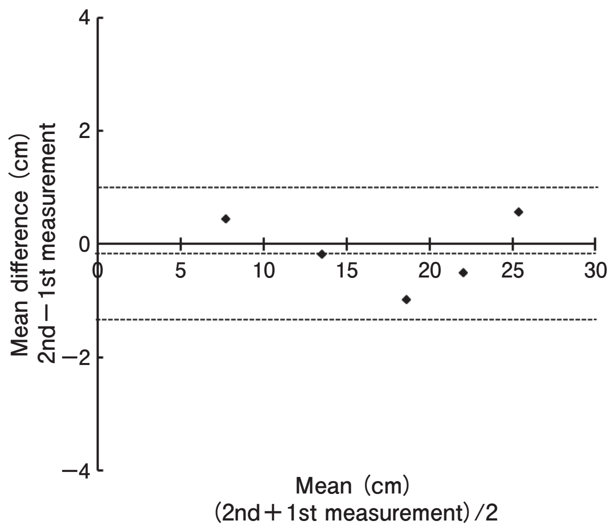

Fig. 3 Bland-Altman plots. The mean differences, which were calculated by subtracting the 1st from the 2nd testing measurement, were not significantly different from 0. These plots show that this is not a systematic error, but is rather a random error. The mean difference was −0.12 cm. The 95% confidence interval (mean ± 1.96 × standard deviation) ranged from −1.26 cm to +1.03 cm.

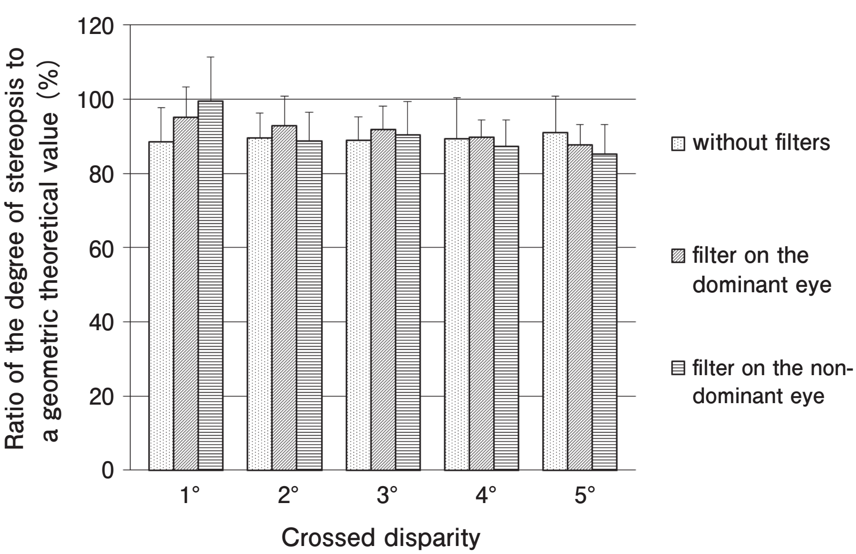

Fig. 4 The ratio of the degree of stereopsis to a geometric theoretical value, with and without 0.3 Bangerter filters, for the 1°–5° disparities. There was no significant difference in the rate of the degree of stereopsis without filters and with the filters placed on the front of the 3D glasses in front of the dominant eye or the non-dominant eye for any of the disparities from 1° to 5°. The error bars are standard deviations.

The degree of stereopsis when a crossed disparity of 0° was used was 0 cm in all subjects.

We assessed the correlation between the stereoacuity measured with the TNO test and the individual average RDS using the theoretical value from 1° to 5°. No significant correlations were observed between the stereoacuity thresholds and the individual average RDS ($p=0.90$).

The mean differences that were calculated by subtracting the 1st from the 2nd testing measurements were 0.44 cm, −0.19 cm, −0.99 cm, −0.51 cm, and 0.56 cm for 1°, 2°, 3°, 4°, and 5°, respectively. None of the mean differences were significantly different from 0 ($p=0.26$, 0.88, 0.06, 0.66, and 0.72, respectively). The Bland-Altman plots [18] are shown in Fig. 3. These plots demonstrate that any errors introduced in this analysis were random and not systematic.

Experiment 2. The corrected visual acuities were decreased by using 0.3 Bangerter filters in all seven subjects. The actual corrected visual acuities of the subjects wearing either glasses or contact lenses and with the 0.3 Bangerter filter in place was 20/63 in both eyes in five subjects, 20/50 in the dominant eye and 20/63 in the non-dominant eye in one subject, and 20/50 in both eyes in one subject.

Fig. 4 shows the degree of stereopsis with and without the 0.3 Bangerter filters for 0°, 1°, 2°, 3°, 4°, and 5° disparities. The RDS without filters were not significantly different for any of the disparities, from 1° to 5°. There was also no significant effect of the filter when placed on the front of the 3D lens in front of either the dominant eye or the non-dominant eye (P-values in the dominant eye in 1°, 2°, 3°, 4°, and 5°: 0.19, 0.40, 0.18, 0.50, and 0.18, respectively; in the non-dominant eye: 0.19, 0.87, 0.61, 0.75, and 0.43, respectively).

Discussion

In this study, we made two clinical observations that addressed the effects of Bangerter filters in healthy adult subjects. First, there was no significant difference in the degree of stereopsis in the presence of Bangerter filters. These data suggested that 0.3 Bangerter filters have no effect on the degree of stereopsis. The use of these filters under treatment for amblyopia may thus be considered relatively safer, in terms of mobility, than occlusion eye patches. Second, there was no significant correlation between the degree of stereopsis and stereoacuity. This suggests that we cannot predict the degree of stereopsis from stereoacuity measured in clinical practice.

Aside from wearing glasses, the most common treatment for amblyopia is occlusion eye patches. It was reported that 0.3 Bangerter filters are a reasonable option for the initial treatment of moderate amblyopia (from 20/40 to 20/63 amblyopic visual acuity) [4,5]. Patients who use a monocular occlusion eye patch over the healthy eye often lose the chance to use both eyes or to have stereo vision. If the patients have normal stereopsis, they lose binocular stereopsis or depth perception, which can increase risks such as falling while walking. However, because the 0.3 Bangerter filters did not affect the degree of stereopsis in the present study, Bangerter filters may be a safer option than occlusion eye patches for amblyopia therapy. Future studies of the effects of Bangerter filters on amblyopia patients are needed to test these findings.

Li *et al.* reported the effects of 0.2, 0.4, 0.6, and 0.8 Bangerter filters on stereoacuity, and they showed a linear reduction in stereo sensitivity (1/stereoacuity thresholds) with increasing Bangerter filter strength [19]. In the present study, although we used 0.3 Bangerter filters (which are recommended for the treatment of moderate amblyopia), we found no differences in the degree of stereopsis with or without 0.3 Bangerter filters. This indicated that 0.3 and stronger Bangerter filters may degrade gross stereopsis.

This study has some limitations. First, only targets with crossed disparity were presented to the subjects because the screen is not transparent and the subjects needed to see the tip of the pen in front of the screen. Further research using targets with uncrossed disparity is needed. Second, the distance between the subject and the screen was short (60 cm). A longer distance would be better to reduce measurement error. However, when the distance exceeds 60 cm, the subject may not be able to indicate the point at which the target pops out from the television screen. We considered 60 cm the best viewing distance based on the results of our preliminary experiment. If a device is developed that allows subjects to indicate the point of the targets from a greater distance, this distance could be extended.

In conclusion, the degree of stereopsis was not degraded by the reduced visual acuity induced by the use of 0.3 Bangerter filters. In this regard, the use of Bangerter filters may be considered safer than occlusion eye patches for patients with normal binocular vision.

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